09:26:22 OCA PAD INITIATION - PROJECT HEADER INFORMATION 03/18/88

Active

Project #: E-20-656
Center # : R6465-0A0

Cost share #: E-20-346
Center shr #: F6465-0A0

Rev #: 0
OCA file #:
Work type : RES
Document : GRANT
Contract entity: GTRC

Contract#: RII-8801537
Prime #:

Mod #:

Subprojects ? : N
Main project #:

Project unit: CE

Unit code: 02.010.116

Project director(s):
RODRIGUEZ-RAMOS W E CE

Sponsor/division names: NATL SCIENCE FOUNDATION / GENERAL
Sponsor/division codes: 107 / 000

Award period: 880401 to 890930 (performance) 891231 (reports)

Sponsor amount	New this change	Total to date
Contract value	12,000.00	12,000.00
Funded	12,000.00	12,000.00
Cost sharing amount		2,232.00

Does subcontracting plan apply ?: N

Title: FUNCTIONAL REQUIREMENTS FOR ANIMATION OF CONSTRUCTION SITE OPERATIONS

PROJECT ADMINISTRATION DATA

OCA contact: Steven K. Watt 894-4820

Sponsor technical contact

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WASHINGTON, D.C. 20550

Sponsor issuing office

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(202)367-9602
NATIONAL SCIENCE FOUNDATION
DGC/STI
WASHINGTON, D.C. 20550

Security class (U,C,S,TS) : U
Defense priority rating : N/A
Equipment title vests with: Sponsor

ONR resident rep. is ACO (Y/N): N
NSF supplemental sheet
GIT X

Administrative comments -
GRANT ISSUED PER LETTER DATED 2/26/88. INITIATION

MAR 1988

OFFICE OF CONTRACT ADMINISTRATION

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 04/30/90

Project No. E-20-656 | Center No. R6465-0A0

Project Director RODRIGUEZ-RAMOS W E | School/Lab CE

Sponsor NATL SCIENCE FOUNDATION/GENERAL

Contract/Grant No. RII-8801537 | Contract Entity GTRC

Prime Contract No.

Title FUNCTIONAL REQUIREMENTS FOR ANIMATION OF CONSTRUCTION SITE OPERATIONS

Effective Completion Date 890930 (Performance) 891231 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	N	
Final Report of Inventions and/or Subcontracts	N	
Government Property Inventory & Related Certificate	N	
Classified Material Certificate	N	
Release and Assignment	N	
Other	N	

Comments

Subproject Under Main Project No.

Continues Project No.

Distribution Required:	
Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other	N
	N

NATIONAL SCIENCE FOUNDATION
Washington, D.C. 20550

FINAL PROJECT REPORT
NSF FORM 98A

PLEASE READ INSTRUCTIONS ON REVERSE BEFORE COMPLETING

PART I—PROJECT IDENTIFICATION INFORMATION

1. Institution and Address	2. NSF Program	3. NSF Award Number
Georgia Institute of Technology School of Civil Engineering Atlanta, GA 30332-0355	MRI-P	RII 8801537
	4. Award Period From 4-01-88 To 9-30-89	5. Cumulative Award Amount $12,000

6. Project Title

Title: Functional Requirements for the Animation of Construction Site Operations.

PART II—SUMMARY OF COMPLETED PROJECT *(FOR PUBLIC USE)*

Review of current work on animation. Determination of the functional requirements of computer graphics' animation and visualization in the construction site. Computer animation integration can be categorized in five levels: (1) The system just acts as a graphics editor for the creation of drawings, (2) The system computes in-between scenes and object trajectory, (3) The system provides object operations such as translation and rotation, (4) The system provides facilities for defining objects which posses their own animation, (5) The system is extensible and can learn. The system continually increases in power and intelligence. Existing key frame animation systems are currently at the level 2. Level 3 and 4 require extensive modeling capabilities. No Level 5 systems are yet available. Animation toolbox testbeds were evaluated and tested with an in-house performance monitoring program. The requirements for construction site animation encompass not only the functional requirements but also the specifications for how the components within such system would interact. A diagram was developed to illustrate the relationship between the logical construction animation components. In addition, a table gives the potential use, goals and methods for the use of animation to simulate construction site operations. As a result of this planning grant, an MRI proposal was developed entitled "Development and Evaluation of a Computer Animation Research Testbed for Construction Site Operations" which is being funded by the NSF.

PART III—TECHNICAL INFORMATION *(FOR PROGRAM MANAGEMENT USES)*

1. ITEM *(Check appropriate blocks)*	NONE	ATTACHED	PREVIOUSLY FURNISHED	TO BE FURNISHED SEPARATELY TO PROGRAM: Check (✓)	TO BE FURNISHED SEPARATELY TO PROGRAM: Approx. Date
a. Abstracts of Theses	✓				
b. Publication Citations	✓				
c. Data on Scientific Collaborators	✓				
d. Information on Inventions	✓				
e. Technical Description of Project and Results					
f. Other *(specify)*					

2. Principal Investigator/Project Director Name *(Typed)*	3. Principal Investigator/Project Director Signature	4. Date
Dr. Walter Rodriguez	Dr. Walter Rodriguez	12-31-89

E-20-656

FINAL REPORT FOR NSF PROJECT RRI 8801537

Walter E. Rodriguez
Georgia Tech
Atlanta, Georgia 30332-0355

1.0 General Data Items

1.1 Title

Functional Requirements for the Animation of Construction Site Operations.

1.2 NSF Program

Minority Research Initiation -- Planning Grant
Tommy E. Wynn, Assoc. Dir., MRI Program

1.3 Award Period

April 1, 1988 to September 30, 1989

1.4 Cumulative Award Amount

$12,000

2.0 Principal Investigator

Walter E. Rodriguez, Associate Professor

3.0 Summary of the Completed Project

Review of current work on animation. Determination of the functional requirements of computer graphics' animation and visualization in the construction site. Computer animation integration can be categorized in five levels: (1) The system just acts as a graphics editor for the creation of drawings, (2) The system computes in-between scenes and object trajectory, (3) The system provides object operations such as translation and rotation, (4) The system provides facilities for defining objects which posses their own animation, (5) The system is extensible and can learn. The system continually increases in power and intelligence. Existing key frame animation systems are currently at the level 2. Level 3 and 4 require extensive modeling capabilities. No Level 5 systems are yet available. Animation toolbox testbeds were evaluated and tested with an in-house performance monitoring program. The requirements for construction site animation encompass not only the functional requirements but also the specifications for how the components within such system would interact. A diagram was developed to illustrate the relationship between the logical construction animation components. In addition, a table gives the potential use, goals and methods for the use of animation to simulate construction site operations. As a result of this planning grant, an MRI proposal was developed entitled "Development and Evaluation of a Computer Animation Research Testbed for Construction Site Operations", (see Sections 4 through 12, i.e., the proposal has been funded by NSF's Structures & Building Systems Division. The following papers were published as a result: Rodriguez, W., and B. Jones, "Animation Tools for Extraterrestrial Construction", *Journal of Aerospace Engineering* (ASCE), Vol. 1, No. 4, pp. 238-247, Oct. 1988; and, Rodriguez, W. and J. Harrell, "A Performance Monitoring Program for CAD User-Interface", Journal of Theoretical Graphics and Computing (STCG), Vol. 2, No. 1, pp. 23-31, Aug. 1989.

NSF Minority Research Initiation Program

DEVELOPMENT AND EVALUATION OF
A COMPUTER ANIMATION RESEARCH TESTBED
FOR CONSTRUCTION SITE OPERATIONS

Walter E. Rodriguez, Ph.D., P.E.
Associate Professor, Engineering Computer Graphics Program
School of Civil Engineering
Georgia Institute of Technology
Project Director and P.I.

4.0 Detailed Project Summary

4.1 Abstract

This NSF research proposal builds on a previous Minority Research Initiation (MRI) planning grant entitled "Functional Requirements for the Animation of Construction Site Operations" (E-20-656, 12 months, $12,000). The purpose of this continued research effort is to develop a new animation (simulation) technique for construction site layout and operations optimization. A new experimental 3-D graphics tool will be developed for use in assessing the value of computer animation in construction site activities; that is, quantitative reporting of user activities and resource utilization. Such reporting capability will make possible the scientific evaluation of computer animation functionality. It would also act as an educational tool that could be use for pedagogical purposes as well as to identify future construction site research problems.

The following tasks will be accomplished during this research effort:

1. Expand the literature review accomplished during the previous planning grant.
2. The design and implementation of animation graphics testbed.
   - A. Develop a monitor toolbox.
   - B. Create a prototype 3-D interface based on a time-multiplexed stereoscopic display system that can be implemented with monitor calls.
3. Assess the validity of the animation testbed concept.
   - A. Evaluate the suitability of the testbed for a specific test, user interfaces for placement of stationary construction cranes.
   - B. Extrapolate results for other tests of the same character.
4. Publish the results in a refereed journal.
5. Develop an interactive video of a construction site animation prototype. This video will be distributed to graduate construction schools in the USA.

4.2 Introduction

The need for improved forms of communication between parties involved in construction [Wilson, 87] suggests the need for a dynamic (animated) representation of the construction process. Computer animation offers a unified approach to modeling the spatial dynamics so crucial in the planning and controlling of construction activities, and in the evaluation of automation models.

The use of animation during remotely monitored or remotely controlled construction processes (e.g., space, undersea, hazardous) could significantly aid the operator of the construction equipment involved [Rodriguez, 88]. For remotely monitored processes simply providing critical information in an easily, and quickly, understood format could aid the human monitor in detecting emergency conditions. Remotely controlled processes may utilize animation and stereoscopic display to provide necessary visual information that would otherwise be unavailable. Both remotely monitored and remotely controlled processes require real-time graphic display possibly incorporating multiple sensor and communication inputs. As a result, fast parallel processors could be essential to the animated representation of multiple construction processes.

The development of automated construction techniques would involve the acquisition and evaluation of knowledge necessary to the candidate process. The animation system could offer an environment to reduce the cost and hazard of evaluating different automation models. The necessary input into the system could be in the form of the animation language generated by the model or algorithm. The developer could utilize the resulting animation sequences to subjectively determine the causes of poor performance or, alternatively, detect potential problems that were not considered in the automation model [Rodriguez, 88].

4.2.1 Rationale for Proposed Approach

While it is perhaps useful to generally ascribe functionality such as the capability for viewing crane work paths [Rodriguez, 82], [Rodriguez, 83] it is more accurate to specifically report the relative usefulness of alternative representation schemes of objects and their behavior. Aspects of presentation such as detail resolution, realism, spatial accuracy and temporal accuracy all play important roles in the understanding of graphic animation sequences. So, in part, the determination of the functionality of animation tools depends upon the tool's value and usability. One step then, in determining functionality, is a quantification of how useful that feature or tool is. Quantitative monitoring and reporting capabilities allow the benefits of hypothetical animation capabilities to be statistically evaluated.

4.3 Background

Conventional animation can be defined as [Magnenat, 85] "...a technique in which the illusion of movement is created by photographing series of individual drawings on successive frames of film. The illusion is produced by projecting the film at a certain rate (typically 24 frames/second)." Computer animation, however, focuses on a number of different aspects of the entire animation process. The computer could be used to create the drawings for each frame, create the motions, color the frames, shoot the sequences, and to edit and synchronize the sequences.

As an illustrative example, animated cartoon films generally start first with a story usually in the form of a written scenario, text only, and a storyboard in which key moments, or sequences, are illustrated. The next step in the animation process is then carried out by animators who draw the key frames. Next, the in-between frames, those frames between key frames, are generated. The frame sequences are then inked and colored on acetate cells. Finally, the photography and editing is done.

The computer can assist in animation in a number of different ways; the computer integration can be categorized in five different levels [Magnenat, 85]:

Level 1: The system basically just acts as a graphics editor for the creation of drawings.
Level 2: The system computes in-between scenes and object trajectory.
Level 3: The system provides object operations such as translation and rotation.
Level 4: The system provides facilities for defining objects which posses their own

animation.

Level 5: The system is extensible and can "learn." The system continually increases in power and intelligence.

Existing key frame animation systems are currently at the Level 2. Level 3 and 4 systems require extensive modeling capabilities. No Level 5 systems are yet available.

Animation has proven valuable in hostile and dangerous environments as a tool for visualizing future actions. For example, when ice built up dangerously on a nonvisible portion of the space shuttle precise animation sequences were used by the NASA Mission Planning and Analysis Division to examine the operation before it was attempted [Roberson, 87]. Advertising and video firms are widely using sophisticated (and expensive) animation sequences to communicate ideas effectively [Wight, 87]. The recent developments in computer animation languages [Magnenat-Thalmann, 85; Gourret 89; Guenter 89] suggests a comprehensive approach to representing complex knowledge about construction material and processes. Additionally, when coupled with a knowledge base and an expert system [Magnenat-Thalmann, 85] the animation system could serve as the visual interface to a system providing access to integrated diverse databases.

The ability to generate predictive animation sequences is especially important in automating construction processes. Recent work in robotics point to the need for predictive knowledge in scene understanding. Clearly, if machines are to begin to understand a complex scene then the components of the scene must be meaningful. The ability to animate construction processes will allow machines to predict the nature and location of scene components thereby dramatically increasing the likelihood of correct understanding. Additionally, predictive animation sequences do not have to be limited to the visible spectrum. A wide range of sensors are available for non-visible portions of the electromagnetic spectrum. The same predictive capability will be necessary for these non-visible sensors, like infrared, near-infrared, LADAR and RADAR.

Human understanding of non-visible sensor imagery is also a potential source of problems in the construction environment of the future. Remotely controlled construction vehicles, or platforms, or simply remotely monitored autonomous equipment could reasonably utilize non-visible sensor displays much as existing navigation and munitions targeting systems do. This assertion is reasonable in light of the necessity for providing the operator, or human monitor, with enough visual cues from sensors that have to operate in environments where normal lighting and, consequently, normal visible imagery is impossible or useless. An example of almost impossible lighting conditions might be undersea conditions where any activity might fill the surrounding water with an impenetrable cloud of particles. Another example of useless visible imagery would be the case where the object or area of interest is between the camera and the sun (or glare from the sun or other major light sources like explosions, fires, etc.). In all of these cases where alternative non-visible sensor imagery would have to be understood by humans the training capabilities provided by non-visible animation sequences might prove invaluable. Much of the non-visible sensor imagery is simply not intuitively obvious to people used to understanding visible light.

To evaluate the impact of lighting conditions on visual cues available to a human monitor, and to produce meaningful non-visible sensor imagery, simple geometric or artistic renderings of the construction environment are inadequate. Rendering techniques which accurately model the transfer of radiant energy in the environment are required. A great deal of research has been done recently on the physically accurate generation of photorealistic computer images. Physically accurate techniques include radiosity methods [e.g. Cohen and Greenberg, 85; Wallace et al., 87; Rushmeier and Torrance, 87] and Monte Carlo methods [e.g. Kajiya, 86; Ward et al., 88]. Such images have been used in illumination design [e.g. Kaneko et al., 88; Ward, 89]. The study proposed here would be among the first to examine the utility of these physically accurate techniques in an engineering design application outside of illumination engineering.

The first step in determining functional requirements for uses of computer animation in construction is the enumeration and description of the basic uses of animation in construction. We see the potential uses of animation in construction in all phases of the planning, design, and execution of terrestrial and extra-terrestrial construction. The following table (see Table 1) summarizes the goals and possible methodology of the proposed animation uses.

Table 1. ANIMATION IN CONSTRUCTION

POTENTIAL USE	GOALS	METHOD
1. Planning of Facility	Aid in activity staging.	Automatic visualization based on construction simulation input.
	Aid in resource conflict detection	Visualization based on CAD object models and motion prediction.
2. Interactive Design of Facility	Assist designer in visualizing the construction impact of a design decision.	Visualization based on CAD object models and knowledge base of construction techniques for different object type and site resources.
3. Real-Time Control and Monitoring of Construction Processes	Allow safe and efficient use of robotic and remotely controlled equipment and operations.	Provide computer generated imagery fusing visible and non-visible sensor imagery as needed with superimposed synthetic views of construction activities.
4. Education and Training	Train design and construction personnel in techniques.	A simulator for operation or monitoring of remote equipment.

Table 1. Animation in Construction Site Operations.

5.0 Description of Research and Development

5.1 Tasks

The following tasks will be accomplished during the project:

5.1.1. Continue the literature review accomplished during the previous planning grant.

The initial MRI planning grant allowed the principal investigator to survey the current animation literature and investigate potential applications to construction site operations. The review will be extended to cover issues as they arise in the course of developing the animation tools and experiments discussed in this proposal.

5.1.2. The design and implementation of animation graphics testbed.

This task will include the definition of the detailed functional requirements for the software, for the user-interface, and detailed design and implementation of the testbed. The functions defined will be those of greatest use in determining measures suitable for evaluating animation interface usability and benefit. In part, this will include specification of the terms "usability" and "benefit" relative to construction site animation.

The design and implementation will require decisions about the primary approach. Potential approaches to be considered are extensions to existing procedural languages and creation of entirely new computer animation languages. For example a functional library for the C language would allow development of a user interface in the popular and portable C language. Alternatively, a new language for animation of primitive construction site operations could be developed rapidly using the UNIX "yacc" utility to both enhance portability to other research institutions and reduce development time. Other options to be explored include defining functional extensions to LISP or CLOS specifically for site operations.

Decisions will also need to be made about the techniques to be made available to render objects on the computer display. Rendering techniques range in complexity from wireframes requiring only hidden line detection to photorealistic techniques which require ray tracing or radiosity calculations. Many of the intermediate techniques, such as Gouraud shading and simple ray casting are available from commercial packages and can readily be incorporated in the testbed. These intermediate techniques can be used for he majority of testbed applications. For the applications which require accurate modelling of radiant transfer, however, either Monte Carlo or radiosity techniques need to be available. In general these more sophisticated techniques are extremely computationally expensive. To be practical, rather than using commercially available routines, these techniques will need to be implemented and streamlined specifically for the construction animation system.

5.1.3. Assess the validity of the animation testbed concept.

A. Evaluate the suitability of the testbed for a specific test, user interfaces for placement of stationary construction cranes.

As a first experiment a prototype animation application will be developed. The problem chosen is the well defined problem of locating a stationary construction crane on site [Rodriguez, 82]. The crane location problem is especially well suited for this endeavor since the principal investigator have extensive on-site experience with crane models and the constraints are well defined and few in number.

B. Extrapolate results for other tests of the same character.

5.1.4. Education and Human Resources: Publish results in a refereed journal and develop interactive video for presentation to various U.S. graduate construction schools.

Results from the previous planning grant have already been published in a refereed journal of ASCE [Rodriguez, 88]. Likewise, the results of this effort will be made available to the research community in a refereed publication. To provide institutional distribution the investigators will develop an interactive video of a prototype construction site animation for presentation to several Graduate Construction Programs in the U.S. This would created interest and foster research in the area.

6.0 Testbed Equipment

Georgia Tech will supply all the necessary computer hardware and software for this research. Our graphics laboratory equipment consists of UNIX-based Silicon Graphics Workstations (see next section: Hardware Description). The Silicon Graphics Personal IRIS workstations' runs the WAVEFRONT and ALIAS animation software which provides all animation and graphics high-level functionality anticipated for this research endeavor. In addition the programming language development environment includes the C programming language, editor, and graphics libraries.

Hardware Description: Dr. Rodriguez's Graphics Laboratory consists of twenty-four Control Data Corporation (CDC)'s Viking 721 terminals, all connected to GTNet via network interface unit (NIU). In addition, 21 high resolution Silicon Graphics Iris (SGI's, labeled CDC 910-400) UNIX-based workstations (20 @ 8 MB, 8BP, 182 MB Disk; 1 @ 16 MB, 24 BP, Z-Buffer, FPU, 380 MB Disk) are connected together in a Local Area Network (LAN) to two File Savers (1.2 GB Disk, 16 MB, C4-ET00 ethernet controller, one server with a 1/2" tape transport capable of handling 6250 bpi densities) and bridged to the GTNet/ethernet backbone in the building. If this proposal is approved Georgia Tech will purchase a Tektronics Liquid Crystal Stereoscopic Shutter and a GEMLOCK w/NTSC encoder. (Note: If funds are not available, we will use the system available at the Ga. Tech. Visualization Lab.) These terminals and workstations access the Sequent S81. S81 is a UNIX-based timesharing, database and parallel processing system. It contains 10 Intel 80386 CPUs, each rated at 4 MIPS. Each CPU has 64 kilobytes of cache memory (access to 96 megabytes of shared memory), 80387 floating point coprocessor and Weitek 1167 floating point accelerator selectable at compile time. Nine gigabytes of local disk storage is installed. The operating system contains support for virtual memory (256 megabyte address space per process), parallel programming, enhanced on-line debugging, TCP/IP communications, and SUN's Network File System.

7.0 Monitor Design

Overall monitor design will emphasize reusable software utilities and modularization to enhance program reliability and reusability. As a minimum the monitor functionality will include counters, timers, report generators and statistic functions. Alternatively, the use of a special purpose animation language for construction operation primitives will be considered. (Note: The principal investigator has had previous experience with the development of CAD monitors [Rodriguez, 89].)

8.0 Monitor Usage

The proposed effort will focus on the use of the graphics testbed in evaluating usability of graphics user interfaces. For example, determining the significance of spatial and temporal resolution of animation sequences would depend, in part, on the user's utilization of that information. The testbed concept is, on the other hand, appropriate to the evaluation of performance improvements of the implementation of graphics applications as well as alternatives for application design. For instance, animation primitives could be implemented as either conventional critical frame systems or as functional programming languages. However, the functionality of animation systems is more readily measured at the user interface than at the application implementation level, thus this research development will focus on reporting-tools for the user-interface.

This effort will include, in addition to the development of the animation testbed, the evaluation of prototype user-interfaces for placement of stationary construction cranes. Issues related to stationary crane placement upon a construction site include the staging of adjacent structural construction, access to material staging areas, crane arm interference, crane cable interference, and operator visibility.

User-interface alternatives of interest in the placement of stationary cranes includes definition of the pertinent site data related to staging areas, crane geometry, and crane trajectories. In addition, alternatives for presenting interference with other structures and vehicles, as well as staging area status will be investigated.

Reporting functions to be used in this experiment will include functions used, commands used, command arguments used, elapsed time (total and by function), and errors (total and by function). These measures will allow a determination of user-interface benefit. The extent to which these measures are effective will be assessed and evaluated.

9.0 Initial Research Questions

1. How have other researchers approached the design and implementation of software monitor utilities?
2. What functions of computer animation are most applicable to construction site animation?
3. What measures are most useful in determining usabilility and benefits?
4. Setting up the reporting tools within the framework of the animation software.
    a. Creation of a library of software functions
    b. Creation of an animation language for construction operation primitives.
5. Definition and implementation issues for a potentially generic experiment toolbox. What aspects of animation applications can be considered common

to all applications? How can tools be developed to assist in their definition?
6. Defining and implementing a user-interface to the animation system that supports three-dimensional concepts.

10.0 Impact of Proposed Research
Animation tools will be important in the following areas:

1. The development of construction simulation models.
2. The development of construction "trainers."
3. The development of knowledge bases for construction.
4. The evaluation of automation models and algorithms.
5. Visual communication between participants in the construction process.

Our efforts will present the details of the hardware and software architecture of the computer graphics testbed, the specific graphic application software tested, the monitor software toolbox, and the summary statistics on the tests themselves. The graphics testbed will be useful in evaluating both user interface functionality as well as alternative designs and implementations of graphics applications. For the first time engineering computer animation alternatives have the potential to be evaluated objectively based on statistical measures of user benefit.

11.0 References (Note: Per NSF criteria, please use the publications marked with asterisk (*) for your review.)

[Bray 85] Gary Bray and David Pokrass. Understanding Ada: A Software Engineering Approach. John Wiley & Sons, New York, NY, 1985.

[Cohen 85] Michael F. Cohen and Donald P. Greenberg. The Hemi-Cube: A Radiosity Solution for Complex Environments. ACM Computer Graphics, Vol. 19, No. 3, 1985, pp. 31-40.

[Greif75] I. Greif and C. Hewitt. Actor semantics of planner-73. Proceedings of ACM SIGPLAN SIGACT Conference, 67-77, 1975.

[Gilbert83] Philip Gilbert. Software Design and Development. Science Research Associates, Inc., Chicago, 1983.

[Goldberg76] A. Goldberg and A. Kay. SMALLTALK-72 Instruction Manual. XEROX PARC, Palo Alto, CA, 1976.

[Hewitt75] C. Hewitt and B. Smith. Towards a programming apprentice. IEEE Transactions of Software Engineering, 26-45, 1975.

[Hodges 85]* L.F. Hodges and D.F. McAllister. "Stereo and Alternating Pair Techniques for Display of Computer-Generated Images." IEEE Computer Graphics and Applications. 5(9), 1985.

[Hodges 88] L.F. Hodges, P. Johnson and R.J. DeHoff. "Stereoscopic Computer Graphics." Journal of Theoretical Graphics and Computing. 1(1), 1988.

[Kahn76] K.M. Kahn. An actor-based computer animation language. MIT AI Working Paper, (120), 1976.

[Kajiya 86] James T. Kajiya. The Rendering Equation. ACM Computer Graphics, Vol. 20, No.4, 1986, pp. 143-150.

[Kaneko 88] T. Kaneko, S. Kikuchi, and S. Takahashi. Computer Graphics System for Lighting Design. Journal of the Illuminating Engineering Institute of Japan, Vol. 72, No. 11, 1988, pp. 652-656.

[Magnenat85] Nadia Magnenat-Thalmann and Daniel Thalmann. Computer Animation Theory and Practice. Springer-Verlag, Tokyo, 1985.

[Magnenat85] Nadia Magnenat-Thalmann, Daniel Thalmann, and Mario Fortin. Miranim: an extensible director-oriented system for the animation of realistic images. IEEE Computer Graphics and Applications, 61-73, March 1985.

[Gourret 89] Jean-Paul Gourret, Nadia Magnenat-Thalmann, Daniel Thalmann. Simulation of Object and Human Skin Deformation in Grasping Task. Computer Graphics, 23(3), SIGGRAPH Proceedings, 21-31, July 1989.

[Guenter 89]* Brian Guenter. Computer Simulation of Facial Expression. Proceedings of Computer Animation '89, June 21-23, 1989, Geneva, Switzerland. (Ed: Springer Verlag).

[Pratt75] Terrence W. Pratt, Programming Languages: Design and Implementation. Prentice-Hall, Inc., Englewood Cliffs, NJ, 1975.

[Reynolds82] C.W. Reynolds. Computer animation with scripts and actors. Proceedings SIGGRAPH '82, Computer Graphics, 16(3), 1982.

[Robertson87] Barbara Robertson. Animation for engineering. Computer Graphics World, 46-50, February 1987.

[Rodriguez82] Walter E. Rodriguez-Ramos. "Quantitative Techniques for Construction Site Layout Planning." Doctoral dissertation presented to the University of Florida. Gainesville, Fl., 1982.

[Rodriguez83]* Walter E. Rodriguez-Ramos and Richard Francis. "Single Crane Location Optimization." Journal of Construction Engineering and Management. A.S.C.E., 109(4), 1983.

[Rodriguez87] Walter E. Rodriguez-Ramos. "Micrographics Construction Site Layout." Journal of Microcomputer Applications. ACCESS, 6(6), 1987.

[Rodriguez88]* Walter E. Rodriguez-Ramos and Barney Jones. "Animation Tools for Extraterrestrial Construction." Journal of Aerospace Engineering. ASCE, 1(4), 1988.

[Rodriguez89]* Walter E. Rodriguez and James Harrell. "User Performance Monitoring Tool for Graphics' Systems Interfaces." Journal of Theoretical and Computational Graphics. STCG, 2(1), 1989.

[Rushmeier 87]* Holly E. Rushmeier and Kenneth E. Torrance. The Zonal Method for Calculating Light Intensities in the Presence of a Participating Medium. ACM Computer Graphics, Vol.21, No. 4, 1987, pp. 293-302.

[Tommeein87] Iris D. Tommelein, Raymond E. Levitt, Barbara Hayes-Roth (Stanford University/ Knowledge System Lab. and Construction Management). "Using Expert Systems for the Layout of Temporary Facilities on Construction Sites". CIB W-65 Symposium 1987. United Kingdom, September 1987.

[Ullman82] Jeffrey D. Ullman. Principles of Database Systems. Computer Science Press, Rockville, Maryland, 1982.

[Wallace 87] John R. Wallace, Michael F. Cohen and Donald P. Greenberg. A Two-Pass Solution to the Rendering Equation: A Synthesis of Ray Tracing and Radiosity Methods. ACM Computer Graphics, Vol. 21, No. 4, 1987,pp. 311-320.

[Ward 88] Gregory J. Ward, Francis M. Rubinstein and Robert D. Clear. A Ray Tracing Solution for Diffuse Interreflection. ACM Computer Graphics, Vol. 22, No. 4,1988, pp. 85-92.

[Ward 89] Gregory J. Ward. RADIANCE: A Tool for Computing Luminance and Synthetic Images. Presented at 1989 IES National Conference.

[Wight87] Jennifer Dritt Wight. The image makers. Computer Graphics World 30-33, February 1987.

[Wilson87] John L. Wilson. National Science Foundation Workshop on Construction Automation: computer-integrated construction. April 1987.

12.0 Miscellaneous Information

12.1 The Principal Investigator has worked independently for the last 5 years. There is no possible conflict of interest to declare. However, it has co-authored some papers with the students listed on 12.2

12.2 Graduate Research Assistants to be contracted (This is also a list of the Ph.D. students supervised by Dr. Rodriguez that will be involved in the project.)

a. Shelley Otero
b. Shane McWhorter
c. Augusto Opdenbosch
d. Barney Jones

12.3 Faculty Consultants to be subcontracted from other departments at Georgia Tech.

Holly (Rodriguez) Rushmeier, Ph.D., P.E. — Ph.D. Advisor: Dr. Donald Greenberg
Assistant Professor, Computer Graphics & M.E. — Cornell University
School of Mechanical Engineering

Larry Hodges, Assistant Professor (StereoGraphics) — Ph.D. Advisor: David McAllister
School of Information and Computer Science — North Carolina State Univ.

Brian Guenter, Assistant Professor (Animation) — Ph.D. Advisor: Bruce Weide
School of Information and Computer Science — Ohio State Univ.

12.4 Resumes of Principal Investigator and Consultants